On the joined AIRS-MLS water vapor (H_2O) product

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1. Motivation

The A-Train provides water vapor (H_2O) retrievals from both the Atmospheric Infrared Sounder (AIRS) and Microwave Limb Sounder (MLS). While AIRS loses sensitivity to H_2O at the elevated portions of the upper troposphere (UT), MLS cannot detect H_2O below 316 hPa. Therefore, to obtain a full profile of H_2O in the whole column of air, we managed to join the two products together by utilizing their own averaging kernels (AK). In doing so, we build a solid H_2O of the whole column of air, which will help us understand the H_2O budget and many processes governing the humidity around the upper troposphere and lower stratosphere (UTLS).

2. How to do it?

The users are strongly recommended to refer Liang et al., [2010, 2011] for more details of the algorithms and the product. Here are just a few pinpoints that worth to mention briefly.

AIRS can retrieve water vapor for P $\geqslant$ 200 hPa with nominal vertical resolutions of ~ 2 – 3 km and horizontal resolution of ~45 km (in footprint diameter). MLS can retrieve water vapor from 0.1–316 hPa with a nominal vertical resolution of ~3 km and its horizontal resolution ranges from ~170 km at 316 hPa to ~230 km at 46 hPa. In order to blend the water vapor information together, we need to collocate AIRS data (in finer resolution) to MLS data (in coarser resolution). For each MLS data, we find the closest AIRS footprint to the MLS. Fig. 1 shows the distance between matched AIRS and MLS footprints for January, 2008. It verifies that 10-98% of the collocated results are between 8-20 km. Because of the coarse resolution of MLS comparing to AIRS, also because AIRS swipes while MLS doesn't, in recording we not only record the closest AIRS footprint to MLS, but also the previous and next AIRS footprints from the closest one along track. In short, each MLS observation will be mapped to three AIRS footprints.

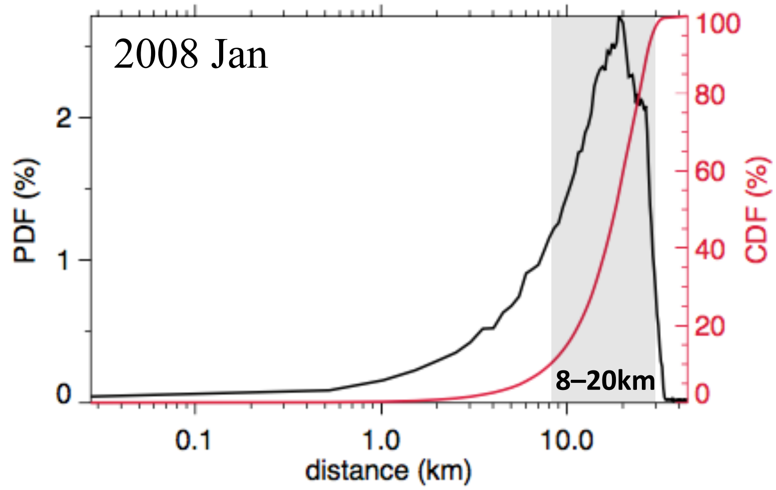

Figure 1. The distances between collocated AIRS and MLS datasets for January, 2008. About 98% of the collocated distances are below 20km.

After finding the collocated measurements of both AIRS and MLS, we utilize averaging kernels (AKs) from both to blend the H_2O together. As shown in **Fig. 2a**, for pressures P < 260 hPa the AIRS verticality (upper Y axis), diagnosed from the AKs, drops dramatically where the AIRS retrieval relies more on the A-prior datasets but the retrieval from radiance. Differently, the MLS verticality closes to one throughout the UTLS (**Fig. 2b**), which means that MLS is sensitive to H_2O throughout the UTLS.

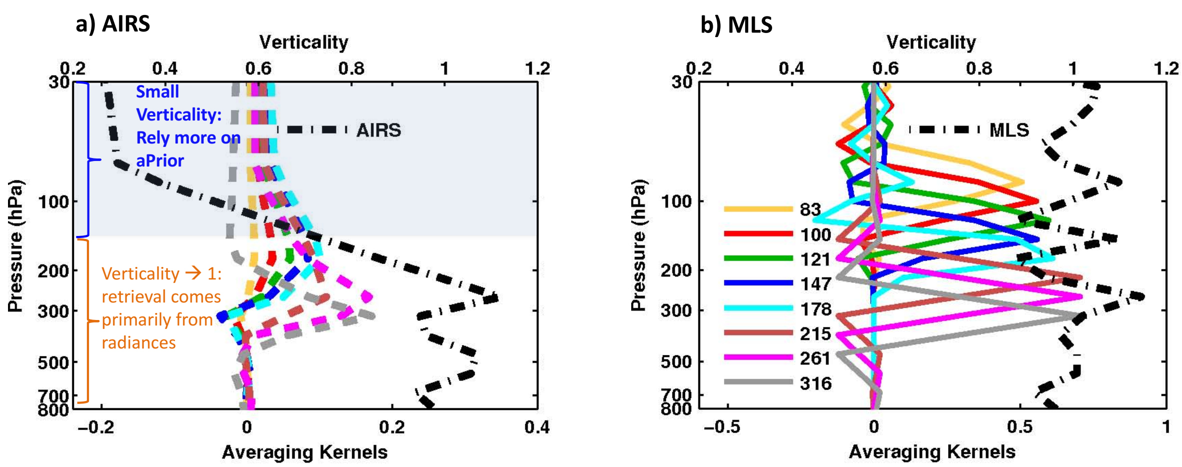

Figure 2. The demonstration of averaging kernels (colored lines, lower x-axis) and verticality (black line, upper x-axis) from a) AIRS and b) MLS. For AIRS, below 260 hPa level its verticality close to one, indicating the retrievals comes primarily from radiances; above the AIRS verticality drops dramatically, where the retrieval relies more on the A-prior datasets. For MLS, the verticality close to one throughout the entire UTLS. (Adapted from Liang et al., [2010])

In-between 316 and 150 hPa, both AIRS and MLS data are useful. While constructing the joined profile, we utilize the AKs from both AIRS and MLS to obtain a weighted mean H_2O, using the relation

$$H_2O_{new} = \frac{w_{AIRS} \times H_2O_{AIRS} + w_{MLS} \times H_2O_{MLS}}{w_{AIRS} + w_{MLS}}$$

where w_{AIRS} and w_{MLS} refer to the weighting factor from both AIRS and MLS AKs, and H_2O_{AIRS} and H_2O_{MLS} refer to water vapor, respectively. **Fig. 3** demonstrates the vertical levels available in the MLS, the AIRS, and the joined datasets. As mentioned, the most blended levels are between 316–150 hPa, where both AIRS and MLS data are useful. As showed in **Fig. 2**, AIRS has more sensitivity and therefore has more weighting when it is close to 316 hPa, whereas MLS is more sensitive at levels above 200 hPa (also see **Fig. 4** below).

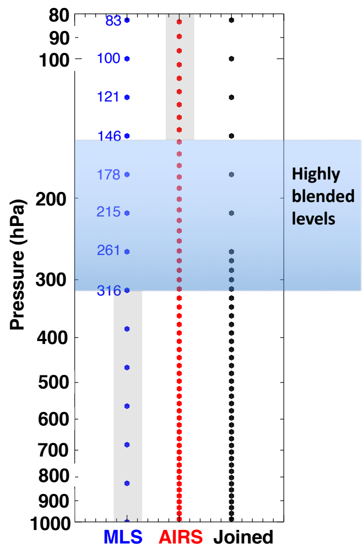

Figure 3. Demonstration of the vertical levels available in MLS (blue), AIRS (red), and Joined (black) datasets. The most blended levels are highlighted in blue shading region.

3. The joined product

3.1 The data structure

The joined data are stored on daily basis. Each day, the ***N*** matched up profiles between AIRS and MLS include:

Name	Description	Unit	Dim	Range
mls_lon	longitude of MLS data	°	N	[-180, 180]
mls_lat	latitude of MLS data	°	N	[-82, 82]
mls_press	Pressure of MLS data	hPa	55 levels	[1000, 10^{-6}]
mls_profile	MLS H_2O profile		[N, 55]	[0.1, 500]
airs_lon2_min	AIRS Longitude Closest to MLS	°	N	[-180, 180]
airs_lon2_bef	AIRS longitude 1 footprint before *airs_lon2_min*	°	N	[-180, 180]
airs_lon2_aft	AIRS longitude 1 footprint after *airs_lon2_min*	°	N	[-180, 180]
airs_lat2_min	AIRS Latitude Closest to MLS	°	N	[-82, 82]
airs_lat2_bef	AIRS Latitude 1 footprint before *airs_lat2_min*	°	N	[-82, 82]
airs_lat2_aft	AIRS Latitude 1 footprint after *airs_lat2_min*	°	N	[-82, 82]

airs_orig_pres	AIRS original pressure levels	hPa	100 levels	[0.01, 1100]
airs_orig_prf	AIRS original H_2O profiles	ppmv	[N, 100]	[0.1, 10^6]
splice_press	Pressure levels of joined data	hPa	78 levels	[0.01, 1100]
splice_profile_min	Joined H_2O profiles by using the closest AIRS to MLS	ppmv	[N, 78]	[0.1, 10^6]
splice_profile_bef	Joined H_2O profiles by using 1 footprint before the closest AIRS to MLS	ppmv	[N, 78]	[0.1, 10^6]
splice_profile_aft	Joined H_2O profiles by using 1 footprint after the closest AIRS to MLS	ppmv	[N, 78]	[0.1, 10^6]
temp_min	Joined temperature profiles by using the closest AIRS to MLS	K	[N, 78]	[160, 330]
temp_bef	Joined temperature profiles by using AIRS footprint before the closest	K	[N, 78]	[160, 330]
temp_aft	Joined temperature profiles by using AIRS footprint after the closest	K	[N, 78]	[160, 330]

*airs_**lon2/lat2**_xxx means the longitude/latitude comes from AIRS L2 data;
*Because AIRS is matched up to MLS, *N* is the practically the size of MLS data for each day;
*Missing values are filled with *NaN.*

3.2 The 2017 updates on Calvin's record.

A few updates have been made on Calvin's original processing and a new updated product has been reprocessed for the available records using the latest MLS (v4.0) and AIRS (v6) data. The updates include:

A. Using the latest MLS and AIRS level 2 products
MLS: v2.2 → v4.0 (level 2)
AIRS: v5 → v6 (level 2 support data, including AKs)

B. Extend the record to the longest available
The joined data has been extended to August 2004 to November 2016 (previously it was only 2005–2009).

C. Update on Calvin's algorithm:
- fix problems on extrapolation;
- add more restrict screening to MLS H_2O;
- optimize structure: more efficient matchup
  Now it takes about 1 week to process 10 years' data (if use all 4 AIRS servers);
- add indices for granule/footprint: easy to trace back

4. Some results

Fig. 4 below compares a random H_2O profile from the MLS (blue for useful levels and light blue for where MLS loses sensitivity), the AIRS (red for useful levels and pink for where AIRS loses sensitivity), and the joined (black) at 179.7^{o}E and 31.1^{o}N on January 1, 2008. Basically, the joined H_2O profile is composed of MLS H_2O at 150-hPa and above levels and AIRS H_2O at 300 hPa and below levels, with the most blended levels between 300 and 150 hPa (highlighted in yellow). This is the region where MLS starts to have more sensitivity but AIRS loses sensitivity.

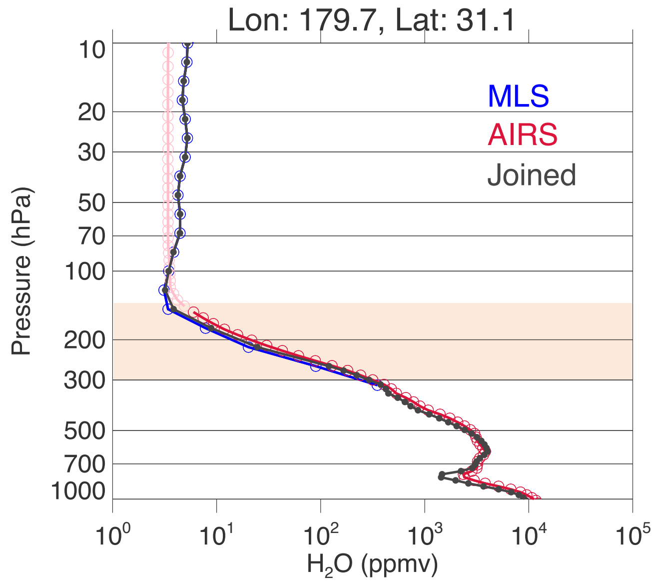

Figure 4. A blended H_2O profile at 179.7°E and 31.1°N on Jan. 1, 2008. Here, MLS data are shown in blue (useful levels) and light blue (levels where MLS loses sensitivity), AIRS data are shown in red (useful levels) and pink (levels where AIRS loses sensitivity), and joined data are shown in black. The most blended regions are highlighted in yellow color.

The most interesting/challenging part of this new product is of course the 300-150 hPa level when data are mostly blended. **Fig. 5** below demonstrates the detailed differences of MLS H_2O (left column), AIRS H_2O (middle column), and the joined H_2O (right Column) at 300, 250, 200, and 150 hPa during January-February (plate a) and July-August (plate b), 2007. It is obvious that starting from 300 hPa to above levels, MLS gradually becomes more sensitive to H_2O and AIRS loses sensitivity to H_2O. Apparently, more weighting on AIRS H_2O at 300 hPa makes the joined H_2O more resembling to that of AIRS, and more weighting on MLS H_2O at 150 hPa makes the joined H_2O more likely to that MLS.

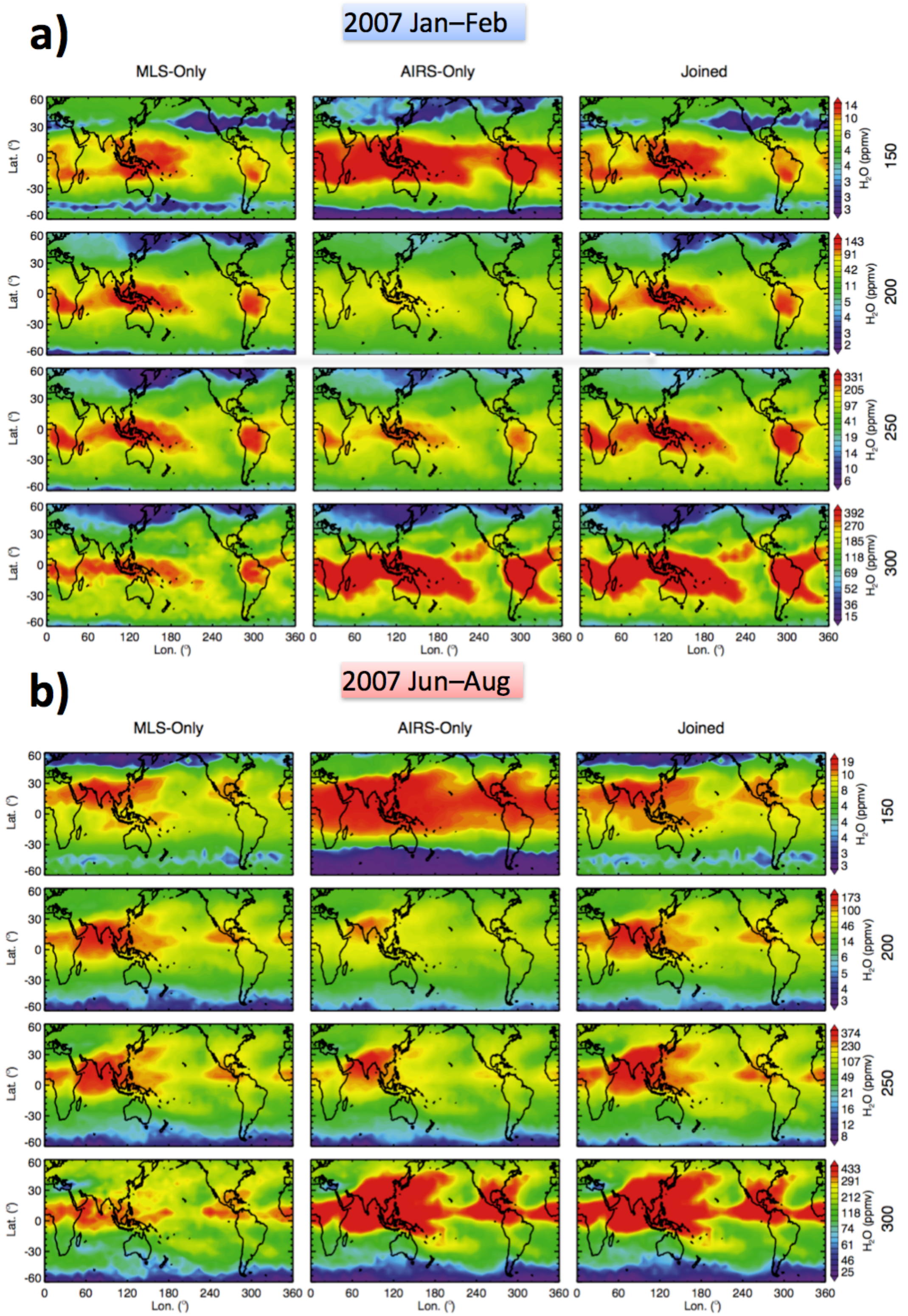

Figure. 5 Comparison of mean H_2O from MLS (first column), AIRS (second column), and the joined (third column) products at 300, 250, 200, and 100 hPa (marked at each row) for a) January-February and b) June-August, 2007, respectively. It is obvious that MLS starts take over at ~250 hPa and above levels, whereas AIRS dominates at and below ~300 hPa.

Fig. 6 shows the time evolution of vertical transport of H_2O viewed from the MLS (panel a), the AIRS (panel b), and the joined dataset (panel c) averaged over the deep tropics (15^o N–S). Note that the color scale is not linear. Starting from the tropopause, the H_2O "tape-recorder" signal due to imprint of tropical tropopause temperatures through "free-drying" of H_2O entering the stratosphere. Again, the new merged H_2O does not change the instrumental interpretation of the atmospheric state that the seasonal variations of H_2O is kept intact.

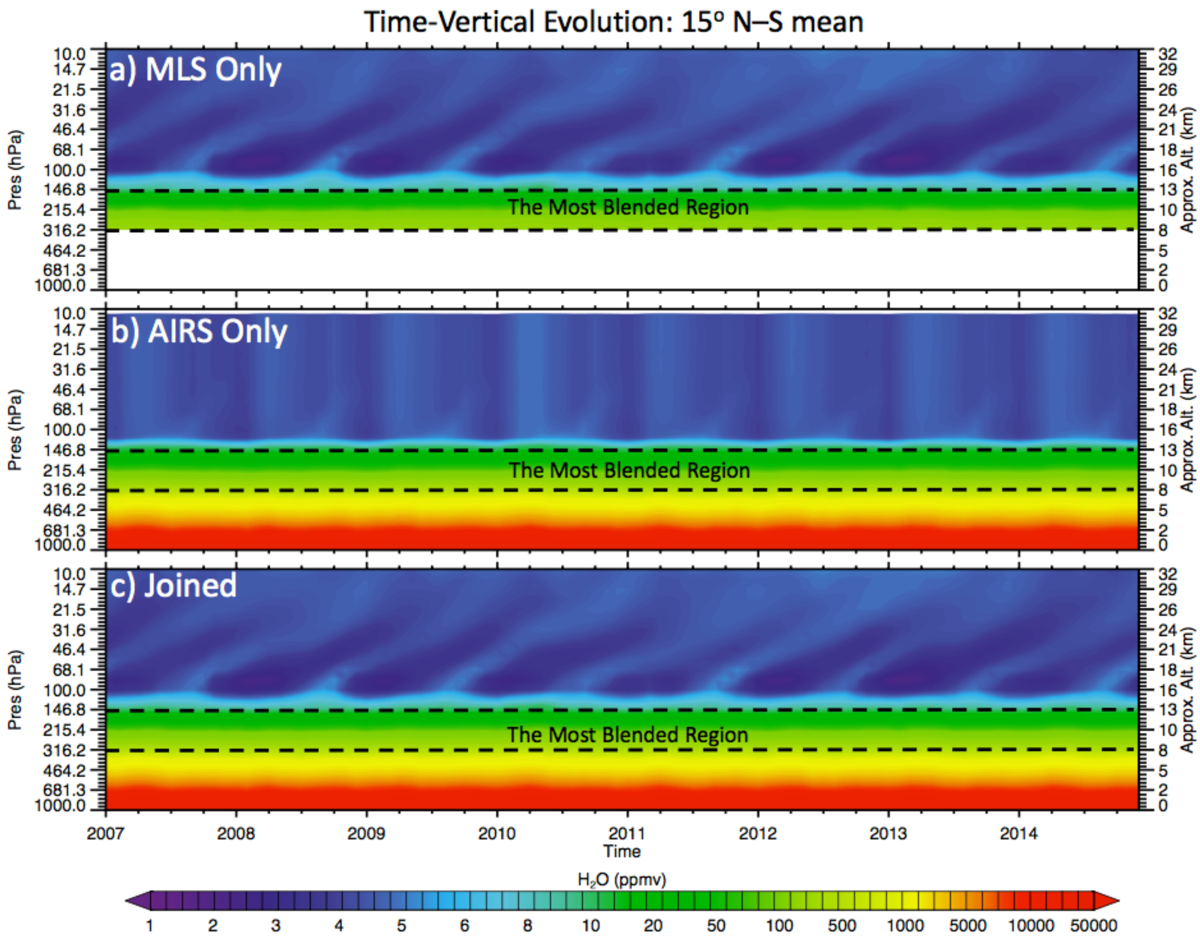

Figure 6. The vertical transport of water vapor in the deep tropics (15^o N–S) shown in MLS data (upper panel), AIRS data (middle panel), and Joined data (bottom panel). The most blended region is marked in dashed lines.

Due to the large range of water vapor from the ground to the stratosphere, it is best to view the H_2O change relative to time mean at each level instead of absolute values. Fig. 7a shows the height-time section of tropical monthly H_2O anomalies from the tropical mean averaged over 15^o N–S. In general, the connection between lower tropospheric H_2O and H_2O at upper troposphere and lower stratosphere is clear: relative to the whole record mean, the moister the air at the troposphere, the drier the air at the stratosphere. This is because the temperature structures at troposphere (e.g., 250 hPa) and stratosphere (e.g, 100 hPa) are reversed in sign due to the fact that the strongest equatorial planetary waves reverse signs at these two levels. This is more clearly seen at the interannual variability of H_2O shown in Fig. 7b, except that for the strong El Nino events such as 2009-2010 that the tropospheric warming associated extends into the tropical tropopause layer and up to the cold point, where it allows for more water vapor to enter the stratosphere.

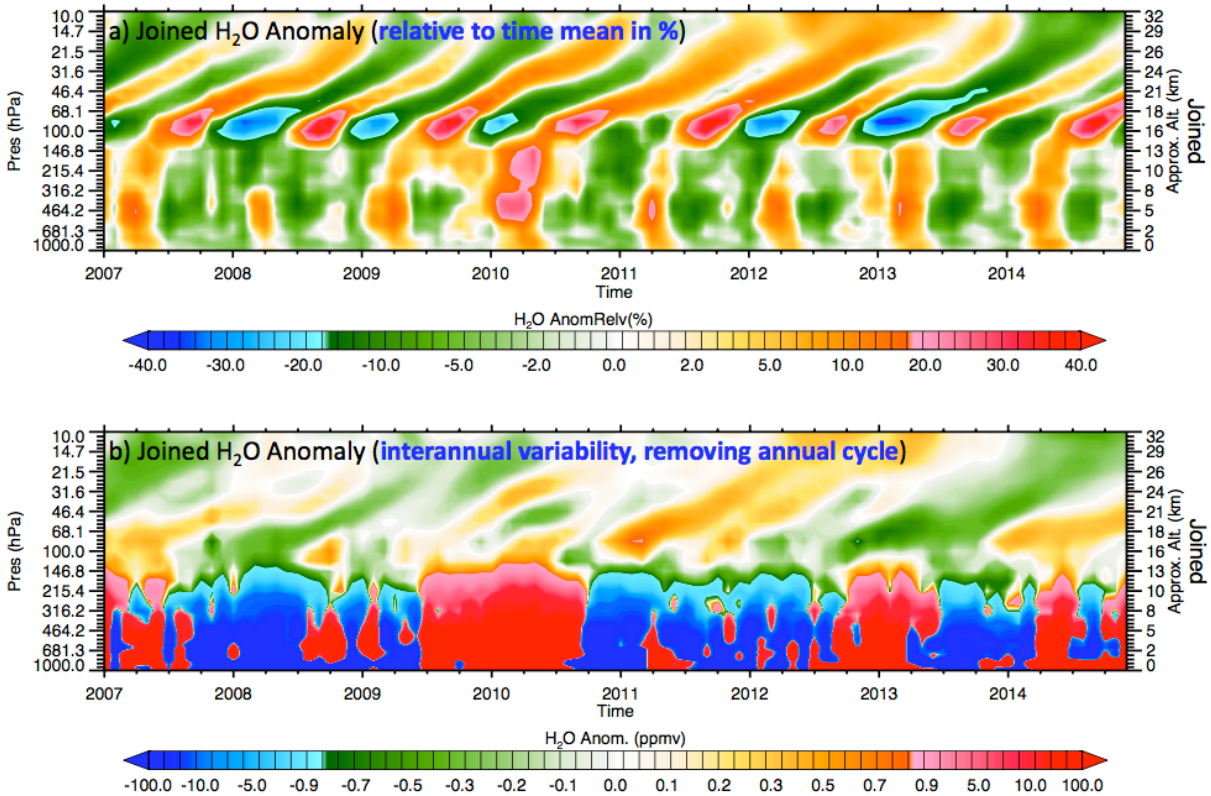

Figure 7. The tape recorder signal shown in anomaly: a) the H_2O anomaly relative to the time mean; b) the H_2O anomaly by removing annual cycles between 2007–2014.

[References]

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